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Enhancement of the Paraffin Wax Performance in the Solar System Collector By Utilizing Alumina (Al_2O_3) Nanoparticles

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Abstract. A nanoparticles composite with phase change material (paraffin wax) was prepared using alumina (Al_2O_3) as a surfactant to improve the dispersion of the Al_2O_3 nanoparticles with (0.5, 1, 3, 5) wt. % in paraffin wax with an Al_2O_3. To evaluate the efficiency of the prepared Phase Change Material (PCMs), the effective thermal conductivity values in the liquid state at a temperature of 60 ºC. The heat storage behavior of the samples was investigated and their melting temperature, latent heat, and thermal reliability were determined. The results showed that the effective thermal conductivity enhancement ratios were 1.5 %, 3 %, 9 % and 15 % for the samples of 0.5 wt. %, 1 wt. %, 3 wt. % and 5 wt. %, respectively. In addition, the dynamic viscosity of the paraffin wax increases excessively with increasing the concentration nanoparticles with paraffin wax. Thus, the results indicate that there is an acceptable dispersion for Al_2O_3 nanoparticles in paraffin wax in concentration by 1 wt. %.

Keywords. Paraffin Wax, Alumina (Al_2O_3), Thermo-physical properties, Thermal storage.

INTRODUCTION

Although Phase Change Material (PCMs) PCMs have been widely used on the thermal energy storage in many applications for the following reasons; the chemical and thermal properties are stable, high latent heat storage capacity, low cost, available, non-toxic, non-corroded, non-harmful to the environment, change volume is small and super-cooling is little. On the other hand, the thermal conductivity of PCMs leads to low heat transfer rate as well as increases the melting and solidification time [1-2]. The heat transfer rate is an important factor for evaluating the performance of thermal energy storage system, and the enhancement of the thermal conductivity is considered as an effective method to improve thermal energy storage system [3]. The high thermal conductivity is an important property of materials utilized for thermal energy storage. Therefore, several types of metals such as nanoparticles are added to improve the thermal conductivity of thermal energy storage materials [4].The adding of nanoparticles to latent thermal energy storage materials leads to enhancing the thermal conductivity and achieves a good thermal performance of energy storage systems [5].

The development in materials properties by utilized nanotechnology in latent energy storage leads to a great opportunity to be used in several industrial and engineering applications such as ; communication engineering system, fields of electronics industries, boiler for power plant and building heating system etc. [6].The enhanced thermo-physical properties of paraffin wax effected by numbers of parameters such as nanoparticles concentration, nanoparticles shape, nanoparticles size and method of preparation. The nanoparticles concentration is considered the major parameter that has the most influence and direct relationship to improvement the thermal conductivity[7]. There are many of recent studies fussing on how enhance the thermo-physical properties of the paraffin wax. The aim of the present study is to increase the thermal conductivity and the dynamic viscosity of the paraffin wax by utilizing Alumina (Al_2O_3) Nanoparticles. Table 1 illustrate brief previous studies showing the effect of adding nanoparticles to paraffin wax in solar systems.

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TABLE 1. Summary for the previous studies showing the effect of adding nanoparticles to paraffin wax

Author	Year	Type of nanoparticles	Size of nanoparticles	wt. %	Result
Shaikhc et al. [8]	2008	SWCNTs, MWCNTs, CNFs	1 nm 10 nm 100 nm	0.1-1	Improvement the latent thermal energy of the paraffin wax by 13 % when add nanoparticle of type SWCNTs at the mass fraction 1 %.
Mahmud et al. [9]	2009	Al_2O_3	80 µm	5	The performance of the solar system enhanced by adding the Al_2O_3 to paraffin wax. So that at the took a discharge time 3.5 h and 8 h at the mass flow rate of 0.19 kg/s and 0.05 kg/s, respectively.
Alkilani et al. [10]	2011	Al_2O_3	70 µm	5	The storage efficiency attained the maximum value 71.9 % for pure paraffin wax and 77.18 % when add the nanoparticles to paraffin wax.
Teng and Chieh Yu [11]	2012	Al_2O_3, TiO_2, SiO2, ZnO	20-30 nm	1.2, 3	By adding TiO_2 nanoparticles to PCM gives a better performance than the other nanoparticles in the improvement of the heat conduction. In addition, TiO_2 decreases the start of melting temperature and increases the start of freezing temperature of PCM.
Dhaidan et al. [12]	2013	CuO	9 nm	1, 3, 5	The addition of CuO nanoparticles to paraffin wax leads to enhancing the thermal conductivity of paraffin wax and increasing the heat transfer rate. In addition, the increasing concentration of nanoparticles results in increasing viscosity, agglomeration and precipitation of the composite.
Dhaidan et al. [13]	2013	CuO	9 nm	1, 3, 5	The addition of the CuO nanoparticles with paraffin wax resulted in improvement of melting characteristics as well as an increase in the thermal conductivity. Therefore, the properties of compound decreased by increasing the concentration nanoparticles due to increase viscosity, agglomeration and precipitation.
Pise et al. [14]	2013	Al_2O_3	20 nm	1, 3, 5	The suspend of nanoparticles with paraffin wax increases the heat transfer rate, thermal energy charging rate and heat release rate compared with the pure paraffin wax.
Wang et al. [15]	2014	TiO_2	20 nm	0.3, 0.5, 0.7, 0.9, 1, 3, 5, 7	They found that the mass fraction 1 wt. % or less which results in latent thermal capacity increases and decreases the phase change temperature. The mass fraction of 3wt. % or more results in the latent thermal capacity decreases and increases the phase change temperature.
Chaichan and Kazem [16]	2015	Al_2O_3	45 µm	1	They found that the addition of Al_2O_3 nanoparticles to paraffin wax improving thermal conductivity as well as increases productivity and time of distillation.
Baydaa J. Nabhan [17]	2015	TiO_2	10 nm	1, 3, 5	At the mass fraction 5wt. % the thermal conductivity increases by around 10 % with increasing temperature 15 °C.
Chaichan et al. [18]	2015	Al_2O_3, TiO_2	30-60 nm 20-50 nm	1, 2, 3, 4, 5	The thermal conductivity of paraffin wax increased when addition the nanoparticles by 65 % and 40 % at mass fraction 5 % for Al_2O_3 and TiO_2, respectively.

Author	Year	Type of nanoparticles	Size of nanoparticles	wt. %	Result
Mohamed et al. [19]	2017	α-Al_2O_3	2-4 nm	0.5, 1, 2	The α-Al_2O_3 nanoparticles additive to paraffin wax leads to enhancement in the latent heat and thermal conductivity by 2 % with the highest effect at 50 °C.
Chaichan et al. [20]	2017	Al_2O_3	30-60 nm	1.2, 3	The thermal conductivity of paraffin wax was enhanced by 18 %, 21 %, and 30 % at the mass fraction 1 %, 2 % and 3 %, respectively.
Tarish and Alwan [21]	2017	CuO	70 µm	10	The thermal storage rate of the CuO nanoparticles with paraffin wax is increased by 30.7 % compared with pure paraffin wax.
Saeed et al. [22]	2017	Fe_3O_4	16.6-30.1 nm	1, 5, 10	Enhancement of the activation energy and latent heat for the paraffin wax after addition of Fe_3O_4 nanoparticles compared with pure paraffin wax. But the range of melting temperature stay the same and unaffected.
Qian et al. [23]	2018	Na_2SiO_3	-	5	The thermal conductivity increasing by 60 % as well as enhancement of the thermal storage efficiency when adding Na_2SiO_3 nanoparticles to paraffin wax.
Purohit et al. [24]	2018	CuO	5-17 nm	1, 2, 3, 4, 5	Increasing the concentration of CuO nanoparticles increases both the latent heat and melting temperature even for mass fraction of 2 %. On the other hand, the latent heat and melting temperature were decreased at the mass fraction higher than 2 %.
Shalaby et al. [25]	2018	α-Al_2O_3	71.5 nm	3	The α-Al_2O_3 nanoparticles with a concentration 3 % increase the thermal conductivity by 18.6 %, and also increasing the thermal effusively by 28.2 %.

METHODOLOGY

Paraffin Wax

Phase change material storage is one of sensible material storage used in low temperature storage applications due to its isothermal storing mechanism and high density of storage. Paraffin wax frequently utilized as PCM in many thermal energy storage systems because it melt at fixed temperature, unreactive, inexpensive and available. The PCM used in the current study is Iraqi paraffin wax as shown in Figure 1. The thermo-physical properties of paraffin wax used in the experiments indicates in Table 2.

FIGURE 1. Thermal energy storage material (paraffin wax)

TABLE 2. Thermo-physical properties of paraffin wax

Property	Value
Latent Heat	176 KJ/kg
Thermal Conductivity	0.21 W/m K
Specific Heat Capacity	2.871 KJ/kg K
Melting Temperature	60 ºC
Freezing Temperature	55 ºC
Liquid Density	770 kg/ m^3
Solid Density	850 kg/ m^3
Dynamic viscosity	0.03499 KJ/m.s

Nanoparticles (AL_2O_3)

Al_2O_3 nanoparticles were purchased in the form of powder by the manufacturer and stored in a clean and dry container. Although the paraffin wax have been widely used for the thermal energy storage in applications of solar systems, but the High thermal resistance for heat transfer among the surface and wax due to the low thermal conductivity. It lead to may not melt a whole of the PCM. To overcome this issue and gets good condition for the PCM, the paraffin wax was mixed with nanoparticles. Alumina Al_2O_3 nanoparticles are stable at a wide temperature range and has high thermal conductivity [26]. Thus it is used as thermal conductivity enhancer.

Generally, Al_2O_3 nanoparticles have many interesting properties, such as high solidity, stability, good insulation, and transparency. [27]. Al_2O_3 nanoparticles widely used in many application for example catalysts, sensor, semiconductors, industry and biomedical field [28]. The thermo-physical properties of Al_2O_3 nanoparticles are presented in Table 3.

TABLE 3. Thermo-physical properties of Al_2O_3 nanoparticles

Property	Value
Color	White
Morphology	Spherical
Purity	99 % (trace metals basis)
Average Particle Size (APS)	40 nm
SSA	60 m^2/g
Thermal Conductivity	40 W/m K
Specific Heat Capacity	765 J/kg K
Density	3970 kg/m^3
Thermal Diffusivity	1.31×10^{-5} m^2/s

Preparation Composites of Paraffin Wax With AL_2O_3

The paraffin wax was bought from Al-Dora refinery Baghdad- Iraq as mentioned earlier, and the Al_2O_3 nanoparticles were purchased in the form of powder by the manufacturer and stored in a clean and dry container. Phases of composite preparation (Nanoparticles with PCM) and calculate its thermo-physical properties as shown in Figure 2.

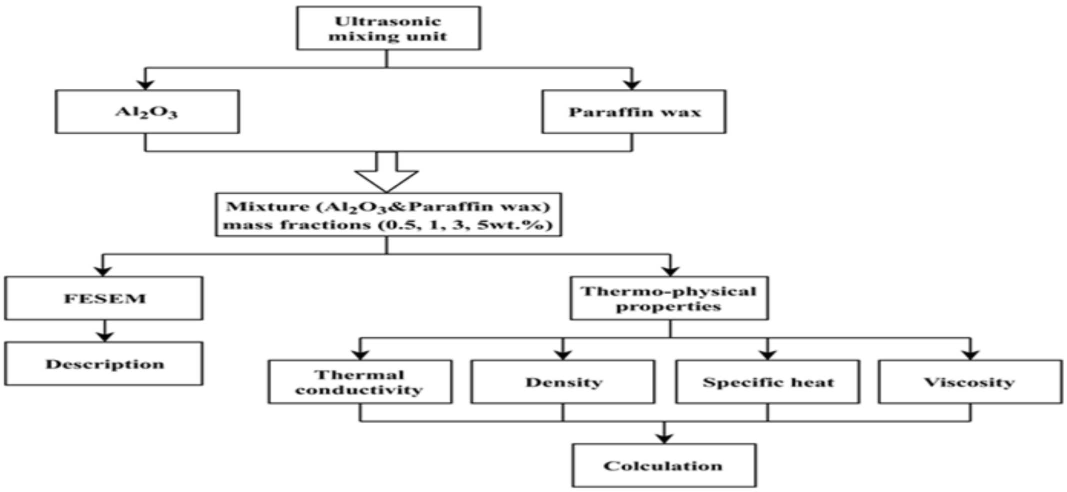


FIGURE 2. Phases of mixture preparation (Al_2O_3 with paraffin wax) and calculate its thermo-physical properties

The mass fraction (φ) of nanoparticles was calculated by the following equation [29]:

$$\varphi = \frac{\left(mass_{np} / \rho_{np}\right)}{\left(mass_{np} / \rho_{np}\right) + \left(mass_{p.w} / \rho_{p.w}\right)} \times 100\% \qquad (1)$$

Two steps were performed to prepare the mixture of paraffin wax and nanoparticles Al_2O_3 with mass friction by (0.5, 1, 3, 5) wt. %. Paraffin wax was molten at 60 ˚C and the nanoparticles was dispersed directly in180 flasks capacity 100 ml and closed by a PVC cap. The ultrasonic water bath utilized Elmasonic P180H type has tank with capacity 18 liters. The flask was mounted to the stainless steel basket inside the ultrasonic water bath. The tank was filled with distilled water above the level of mixture in the flask about 3 cm as shown in Figure. Then, the degas mode is watched on to remove the air from the mixture. Then, the flask is closed by the cap and oscillated continuously for 2 hours in the ultrasonic path water with working at frequency 37 kHz and power efficiency of 100% at 70 °C, until Al_2O_3 nanoparticles are uniformly suspended in paraffin wax. The same preparation conditions were applied to produce all the samples as shown in figure 4.

FIGURE 3. Suspension of Al_2O_3 in paraffin wax by ultrasonic water bath (Elmasonic P180H)

FIGURE 4. View of the pure paraffin wax and Al_2O_3 nanoparticle suspended in paraffin wax with concentration (0.5, 1, 3, 5) wt. %

Thermo-Physical Properties of Composite

In this section the thermo physical properties of the composite were discussed to define the heat transfer coefficient of the composite. The distribution of the nanoparticles in the paraffin wax influence on the thermo physical properties of the composite (mixture) such as thermal conductivity, density, specific heat capacity and viscosity.

Thermal Conductivity of Composite

The composite with low mass fraction of nanoparticles suspension in the PCM gives stability for longer period of time than the composite with high mass fraction. The thermal conductivity of the composite depend on the thermal conductivities of constituents, the concentration of nanoparticles and disperd, Maxwell's equation is adopted evaluating the effective thermal conductivity of composite, as given by this equation [29].

$$k_{comp} = \frac{k_{np} + 2k_{p.w} + 2\varphi(k_{np} - k_{p.w})}{k_{np} + 2k_{p.w} - \varphi(k_{np} - k_{p.w})} \times k_{p.w} \tag{2}$$

Density of Composite

The composite density is influenced by the concentration ratio op nanoparticles and the type of fluid (PCM) when the size and shape of the nanoparticles don't effect the density of composite. The density equation written as flowing [30].

$$\rho_{comp} = (1-\varphi)\rho_{p.w} + \varphi\ \rho_{np} \tag{3}$$

Specific Heat Capacity of Composite

The specific heat capacity of the composite depends on the concentration ratio of nanoparticles, the density of the composite and the heat capacity of composite components. The specific heat capacity equation is given by the following [30].

$$C_{p_{comp}} = \frac{(1-\varphi)(\rho C_p)_{p.w} + \varphi(\rho C_p)_{np}}{\rho_{comp}} \quad (4)$$

Viscosity of Composite

The viscosity is the one of the important parameters in the fluid mechanics applications and described the internal resistance of fluid during flow proses. The heat transfer coefficient and thermal conductivity effect by viscosity in the thermal system. The viscosity of the composite effect by the viscosity of base fluid (PCM) and concentration ratio of nanoparticles. The shape and size of nanoparticles affect the viscosity of the composite. In this study, Brinkman equation [31] to compute the viscosity of the composite was adopted. It is an equation used to calculate the viscosity of the composite containing suspensions of small spherical particles as following.

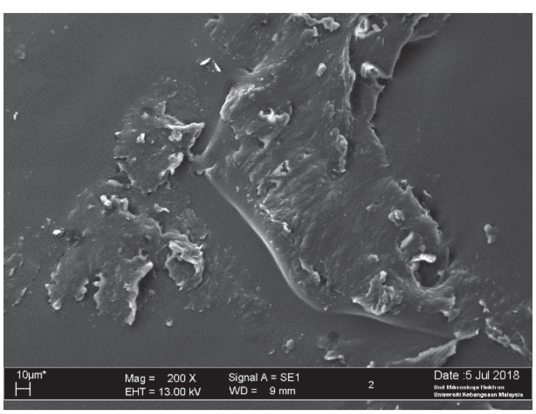
$$\mu_{comp} = \frac{\mu_{p.w}}{(1-\varphi)^{2.5}} \quad (5)$$

Field Emission Scanning Electron Microscopy (FESEM)

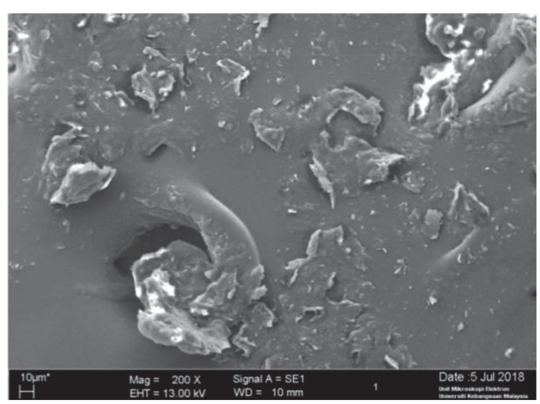
The Field Emission Ecanning Electron Microscope (FESEM) was conducted for samples of Al_2O_3 nanoparticles and paraffin wax with different concentrations in the microscopy electron unit, University Kebangsaan Malaysia (UKM). FESEM device is a microscope that works by electrons instead of light; these electrons are liberated by a field emission source.

RESULTS AND DISCUSSION

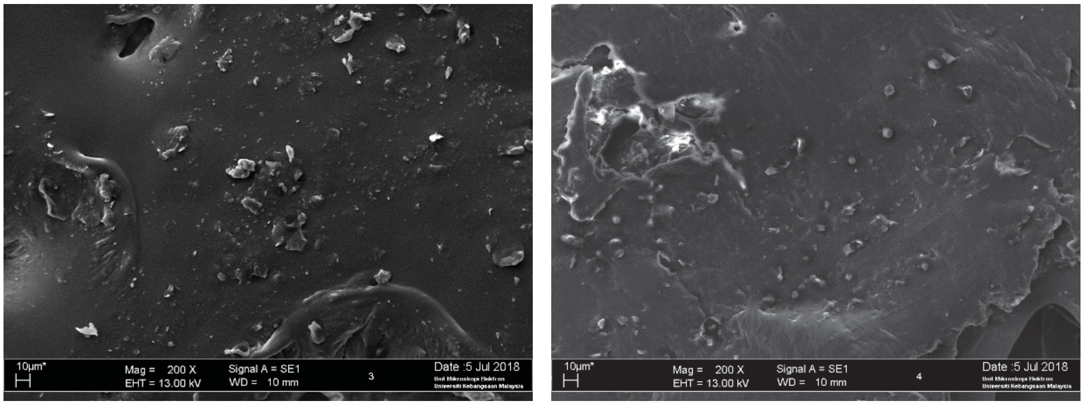
Phase change enthalpy, melting temperature and thermal properties stability are important factors in paraffin wax which affect their efficiency when used in thermal energy storage systems. In this study, Al_2O_3 nanoparticles and paraffin wax were weighed to prepare the samples with different concentrations of (0.5, 1, 3, 5) wt. %. Figure 5 shows image of FESEM for the samples of Al_2O_3 nanoparticles suspension with paraffin wax. The figures indicates that the mixture of Al_2O_3 nanoparticles with paraffin wax has non porous structure. Also, the figures shows that there is an acceptable dispersion of Al_2O_3 nanoparticles in paraffin wax in concentration by 1 wt. %.



(a) concentration nanoparticles with paraffin wax by 0.5 wt. %



(b) concentration nanoparticles with paraffin wax by 1 wt. %



(c) concentration nanoparticles with paraffin wax by 3 wt. %

(d) concentration nanoparticles with paraffin wax by 5 wt. %

FIGURE 5. FESEM image with different concentrations of Al_2O_3 nanoparticles with paraffin wax

The effect of different concentration of nanoparticles suspended in paraffin wax on the thermal conductivity of the paraffin wax is outlined in Fig. 6. From the figure, it is clearly seen that the thermal conductivity of the paraffin wax increasing with increasing concentration of nanoparticles. Where the effective thermal conductivity enhancement ratios were 1.5 %, 3 %, 9 % and 15 % for the samples of 0.5 wt. %, 1 wt. %, 3 wt. % and 5 wt. %, respectively. However, nanoparticles can't be added excessively to paraffin wax because this increases the dynamic viscosity of paraffin wax as shown the figure 7. Finally, Figure 8, illustrate that the proposed composite in present study achieved high thermal conductivity compared to previous studies that are reported in the literature. , it is the most important motivation of the present study.

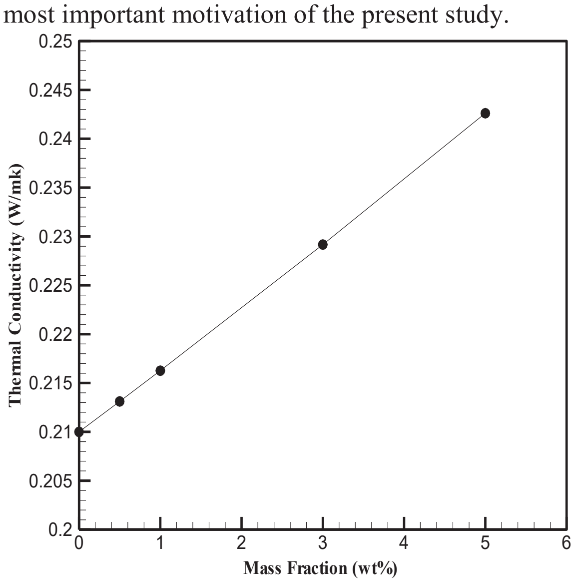


FIGURE 6. Thermal conductivity during the concentration variation for the paraffin wax and alumina composites

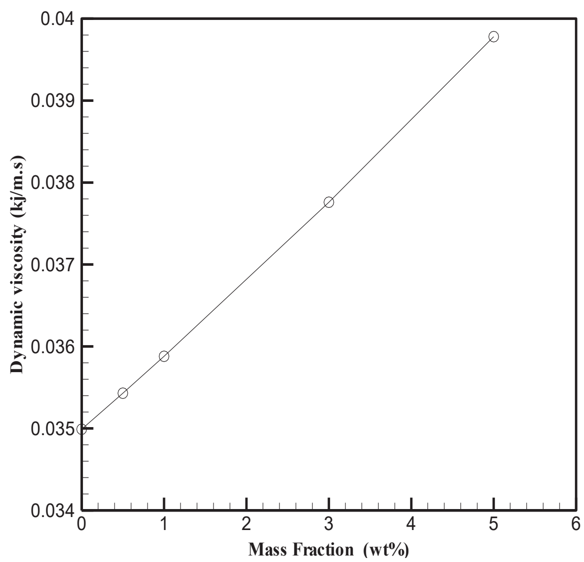


FIGURE 7. Dynamic viscosity during the concentration variation for the paraffin wax and alumina composites

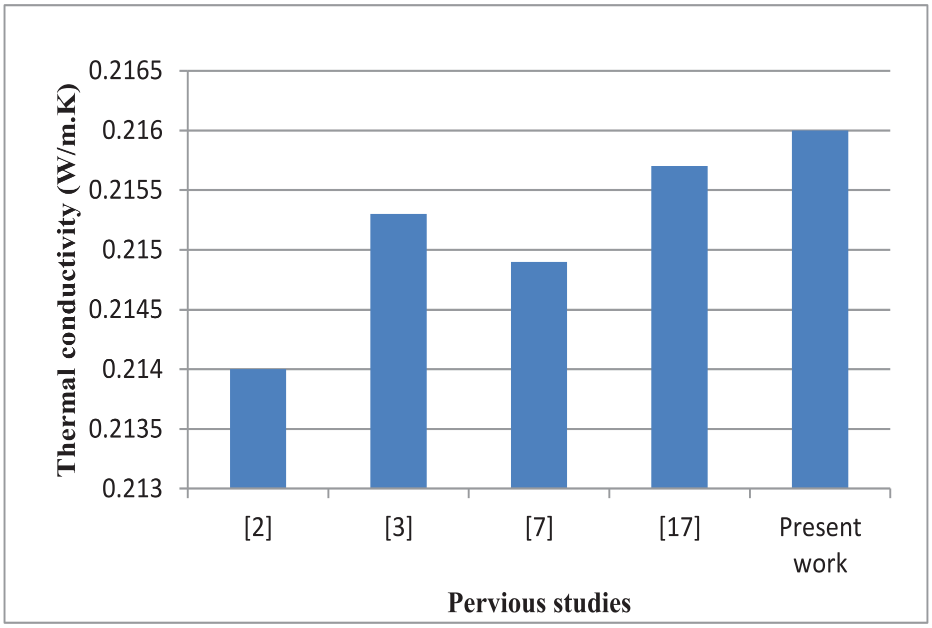


FIGURE 8. Comparison of the thermal conductivity in present study with other studies

CONCLUSION

In this study, Al_2O_3 nanoparticles were employed to enhance the thermal performance of paraffin wax. A series of stable and homogenous paraffin wax with Al_2O_3 nanoparticles (0.5, 1, 3, 5) wt. % to study their thermal behavior. The results showed that the effective thermal conductivity of the composites prepared increased by increasing Al_2O_3 nanoparticles concentration. The highest effective thermal conductivity enhancement ratio was attributed to the nanoparticles composite containing 5 wt. % Al_2O_3 nanoparticles at 60 °C. On the other hand, the dynamic viscosity of the paraffin wax increases excessively with increasing the concentration nanoparticles with paraffin wax. Also, the results indicate that there is an acceptable dispersion for Al_2O_3 nanoparticles in paraffin wax in concentration by 1 wt. %.

NOMENCLATURE

φ	Mass fraction of nanoparticle (%)
$mass_{np}$	Weight of nanoparticles
$mass_{p.w}$	Weight of paraffin wax
ρ_{np}	Density of nanoparticles (kg/m^3)
$\rho_{p.w}$	Density of and paraffin wax (kg/m^3)
ρ_{comp}	Density conductivity of composite (kg/m^3)
k_{np}	Thermal conductivity of nanoparticles (W/m K)
$k_{p.w}$	Thermal conductivity of paraffin wax (W/m K)
k_{comp}	Thermal conductivity of composite (W/m K)
$C_{p_{np}}$	Specific heat capacity conductivity of nanoparticles (kJ/kg K)

$C_{p_{p.w}}$	Specific heat capacity conductivity of paraffin wax (kJ/kg K)
$C_{p_{comp}}$	Specific heat capacity conductivity of composite (kJ/kg K)
μ_{comp}	Viscosity of composite (kg/m s)
$\mu_{p.w}$	Viscosity of paraffin wax (kg/m s)

REFERENCES

1. Y. Lin, Y. Jia, G. Alva, and G. Fang, "Review on thermal conductivity enhancement , thermal properties and applications of phase change materials in thermal energy storage," Renew. Sustain. Energy Rev., vol. 82, no. Oct. 2017, pp. 2730-2742, 2018.
2. Y. Deng, J. Li, and H. Nian, "Solar Energy Materials and Solar Cells Polyethylene glycol-enwrapped silicon carbide nanowires network/expanded vermiculite composite phase change materials : Form-stabilization, thermal energy storage behavior and thermal conductivity enhancement," Sol. Energy Mater. Sol. Cells, vol. 174, no. Aug. 2017, pp. 283-291, 2018.
3. G. Alva, Y. Lin, and G. Fang, "An overview of thermal energy storage systems," Energy, vol. 144, pp. 341-378, 2018.
4. R. Tchinda, "A review of the mathematical models for predicting solar air heaters systems," vol. 13, pp. 1734-1759, 2009.
5. C. Kaviarasu, D. Prakash, "Review on Phase Change Materials with Nanoparticle in Engineering Applications," vol. 9, no. 4, pp. 26–36, 2016.
6. M. Y. A. Jamalabadi, "Effects of Brownian Motion on Freezing of PCM Containing Nanoparticles," vol. 20, no. 5, pp. 1533-1541, 2016.
7. M. M. Tawfik, "Experimental Studies of Nanofluid Thermal Conductivity Enhancement and Applications : A Review *," vol. 75, no. Aug., pp. 1239-1253, 2017.
8. S. Shaikh and K. P. Hallinan, "Carbon Nanoadditives to Enhance Latent Energy Storage of Phase Change Materials," 2008.
9. A. Mahmud, K. Sopian, M. Sohif, and A. M. Graisa, "Using a Paraffin Wax-Aluminum Compound As a," vol. 4, no. Dec. 2009, pp. 74-77, 2009.
10. M. M. Alkilani, K. Sopian, S. Mat, and S. D. Ehsan, "Fabrication and Experimental Investigation of PCM Capsules Integrated in Solar Air Heater Institute of Solar Energy Research , Faculty of Engineering ," vol. 7, no. 6, pp. 542-546, 2011.
11. T. Teng and C. Yu, "Characteristics of phase-change materials containing oxide nano-additives for thermal storage," Nanoscale Res. Lett., vol. 7, no. 1, p. 1, 2012.
12. N. S. Dhaidan, J. M. Khodadadi, T. A. Al-hattab, and S. M. Al-mashat, "Experimental and numerical investigation of melting of phase change material/nanoparticle suspensions in a square container subjected to a constant heat flux," Int. J. Heat Mass Transf., vol. 66, pp. 672-683, 2013.
13. N. S. Dhaidan, J. M. Khodadadi, T. A. Al-hattab, and S. M. Al-mashat, "Experimental and numerical study of constrained melting of n -octadecane with CuO nanoparticle dispersions in a horizontal cylindrical capsule subjected to a constant heat flux," Heat Mass Transf., vol. 67, pp. 523-534, 2013.
14. A. T. Pise, A. V Waghmare, and V. G. Talandage, "Heat Transfer Enhancement by Using Nanomaterial in Phase Change Material for Latent Heat Thermal Energy Storage System," vol. 2, no. 2, pp. 52-57, 2013.
15. J. Wang, H. Xie, Z. Guo, L. Guan, and Y. Li, "Improved thermal properties of paraf fi n wax by the addition of TiO2 nanoparticles," vol. 73, pp. 1541-1547, 2014.
16. M. T. Chaichan and S. H. Kamel, "Using Aluminium Powder with PCM (Paraffin Wax) to Enhance Single Slope Solar Water Distiller Productivity in Baghdad-Iraq Winter Weathers," vol. 5, no. 1, pp. 251-257, 2015.
17. B. J. Nabhan, "Using Nanoparticles for Enhance Thermal Conductivity of Latent Heat Thermal Energy Storage," vol. 21, no. 6, pp. 37-51, 2015.
18. M. T. Chaichan and H. A. Kazem, "Thermal Conductivity Enhancement by Using Nano-Material in Phase Change Material for Latent Heat Thermal Energy Storage Systems," vol. 5, no. 6, pp. 48-55, 2015.
19. N. H. Mohamed, F. S. Soliman, H. El, and Y. M. Moustfa, "Thermal conductivity enhancement of treated petroleum waxes , as phase change material , by α nano alumina : Energy storage," Renew. Sustain. Energy Rev., vol. 70, no. Oct. 2015, pp. 1052-1058, 2017.

20. M. T. Chaichan, R. M. Hussein, and A. M. Jawad, "Thermal Conductivity Enhancement of Iraqi Origin Paraffin Wax by Nano-Alumina," vol. 13, no. 3, pp. 83-90, 2017.
21. A. L. Tarish and N. T. Alwan, "Experimental Study of Paraffin Wax-Copper Nanoparticles Thermal Storage Material," vol. 3, no. 3, pp. 11-17, 2017.
22. F. R. Saeed et al., "Nanomagnetite Enhanced Paraffin for Thermal Energy STORAGE Applications," vol. 12, no. 2, pp. 273-280, 2017.
23. Z. Qian, H. Shen, X. Fang, L. Fan, N. Zhao, and J. Xu, "Phase change materials of paraffin in h-BN porous scaffolds with enhanced thermal conductivity and form stability," Energy Build., vol. 158, pp. 1184-1188, 2018.
24. K. Purohit, M. Dhonde, K. Sahu, and V. V. S. Murty, "ISSN NO : 2394-8442 Latent heat enhancement using CuO nanoparticles in paraffin for thermal energy storage applications," vol. 5, no. 2, pp. 798-806, 2018.
25. S. M. Shalaby, H. F. Abosheiash, S. T. Assar, and A. E. Kabeel, "Improvement of Thermal Properties of Paraffin Wax as Latent Heat Storage Material with Direct Solar Desalination Systems by Using Aluminum Oxide Nanoparticles Keywords : Water desalination , Nanoparticles , Thermal conductivity Samples preparation," no. June, pp. 28-30, 2018.
26. A. Mukherjee, M. S. I, T. C. Prathna, and N. Chandrasekaran, "Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications," pp. 245-251, 2011.
27. A. Khazaei, S. Nazari, G. Karimi, and E. Ghaderi, "Synthesis and Characterization of γ -Alumina Porous Nanoparticles from Sodium Aluminate Liquor with Two Different Surfactants," vol. 12, no. 4, pp. 207-214, 2016.
28. V. Piriyawong, V. Thongpool, P. Asanithi, and P. Limsuwan, "Preparation and Characterization of Alumina Nanoparticles in Deionized Water Using Laser Ablation Technique," 2012.
29. W. Yu and S. U. S. Choi, "The role of interfacial layers in the enhanced thermal conductivity of nanofluids : A renovated Maxwell model," pp. 167-168, 2003.
30. L. C. C. and J. K. Zhong, "Thermal Conductivity Enhancement for Phase Change Storage Media," vol. 23, pp. 91-100, 1996.
31. H. C. Brinkman, "The Viscosity of Concentrated Suspensions and Solutions," vol. 571, pp. 1-2, 1952.